Effects of adding water on seasonal variation of soil nitrogen availability under sandy grasslands in semi-arid region

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Abstract: Water is usally thought of a limiting factor for the restoration of semi-arid ecosystem. In the growing season of 2006, a study was conducted to determine the effects of modeling precipitation on seasonal patterns in concentrations of soil-available nitrogen and to describe the seasonal patterns in soil nitrogen availability and seasonal variation in the rates of net nitrogen mineralization of topsoil at Daqinggou ecological station in Keerqin sand lands, Inner Mongolia Autonomous Region, China. Manipulation of water (80 mm) was designed to be added to experiment plots of sandy grasslands in dry season. Water addition (W) treatment and control (CK) treatment were separately taken in six replications and randomly assigned in 12 plots (4 m×4 m for each) with 2-m buffers betweens. Results showed that the content of soil inorganic nitrogen and net nitrogen mineralization rate were not affected by adding water in sandy grassland of Keerqin sand lands. Net nitrogen mineralization rates ranged from 0.5 $\mu g \cdot g^{-1} \cdot month^{-1}$ to 4 $\mu g \cdot g^{-1} \cdot month^{-1}$. The highest values of soil inorganic nitrogen and net nitrogen mineralization occurred on October 15 in control plots. The seasonal changes of soil inorganic nitrogen contents exhibited "V" shape pattern that was related to seasonal patterns of soil ammonium-N (ascending trend) and nitrate-N transformation (descending trend).

Keywords: Nitrogen mineralization; Inorganic nitrogen; Grassland; Keerqin sand lands; Nitrification

Introduction

Nitrogen is a macronutrient essential to plants, but one of the most deficient soil nutrients in terrestrial ecosystems (Vitousek *et al*. 1991). Arid and semi-arid ecosystems comprise 30%–40% of earth's terrestrial biomes and are increasing in area. Controls on nitrogen cycling in these systems are poorly understood relative to their importance in terms of land coverage (Schaeffer *et al*. 2003). Nitrogen cycles in arid ecosystems have historically been characterized by relatively low nitrogen availability, low rates of inputs via atmospheric deposition and N_2-fixation, and relatively high rates of gaseous loss of NO_x, N_2O, N_2 and NH_3 (Peterjohn *et al*. 1990). Soil nitrogen availability for plants at any points in time and space reflects the balance between the processes of: (i) mineralization from decomposing soil organic matter (newly added residues, existing degraded residues of varying age and degree of recalcitrance, and microbial biomass); (ii) immobilization in soil microbial biomass; (iii) plant uptake; (iv) depositions;

and (v) losses (denitrification and leaching).

There is a growing scientific awareness that how changes in precipitation regimes may affect terrestrial ecological systems (Schaeffer *et al*. 2005). Low rainfall is the primary constraint on biological activity in arid and semi-arid ecosystems (Sala *et al*. 1988), so changes in the intensity, frequency, and seasonality of precipitation may affect primary production, decomposition, trace gas flux, and other aspects of biogeochemical cycling. Wetting of the extremely dry (-5 to -10 MPa) soil usually causes a release of inorganic nitrogen, which may be taken up by plants (Ivans *et al*. 2003). Numerous studies over the last few decades have demonstrated that net nitrogen mineralization increased with wetting of dry soil (Cui *et al*. 1997; Saetre *et al*. 2005). Little has been known to have an influence on nitrogen availability in semi-arid ecosystems on sandy soils when raining, whereas many reports showed that there were feedbacks among soil nitrogen mineralization, nitrogen availability, soil moisture and plant water use efficiency in other ecosystems (Hooper *et al*. 1999; Austin *et al*. 2004; Chen *et al*. 2005).

We hypothesize that water is the primary limiting factor for the restoration of sandy grassland ecosystem. In this paper, our study has two specific research objectives: (1) to investigate the effect of simulated precipitation on seasonal patterns in concentrations of soil-available nitrogen and (2) to describe the seasonal variation in the rates of soil net nitrogen mineralization of topsoil in Keerqin sandy grassland.

Study area and methods

Study area

This study was conducted in a permanent grassland site at

Daqinggou ecological station in the south-easten part of the Keerqin Sand Lands, Tongliao, China. Historically, this area was a pastoral zone, but now it is mainly an agropastoral ecotone. The area is a semi-arid region with sandy soils, low precipitation (450 mm·a^{-1}) (Fig. 1), and high potential evaporation (1 780 mm·a^{-1}). The average annual temperature is 6ºC, relative air humidity is 59%; and the average annual frost-free period is 154d (Yu *et al*. 2006). Soil has developed on wind-deposited sands and is characterized by coarse texture and loose structure with greater proportion of sands; thereby, the contents of essential soil nutrient (C, N, and P) are rather low (Table 1).

This site naturally was restored from cropland to grassland in 2000. The vegetation of this site was dominated by *Pennisetum flaeccidum* and *Artimisia scoparia*.

Methods

In 2006, one field experiment was designed in Daqinggou ecological station to study the effects of manipulation of water (80 mm) on key ecosystem processes of nitrogen cycles in sandy grassland. Water addition (W) treatment and control (CK) were taken in 6 replications and randomly assigned to 12 plots (4 m × 4 m for each) which were detached by 2-m buffers. Adding water was carried out by simulating precipitation in dry season in 2006 for 50 mm from April 25 to June 1 and 30 mm from July 27 to August 20).

The rates of net nitrogen ammonification, nitrification and mineralization were estimated through the in situ closed-top core incubation method (Wedin *et al*. 1990) during the growing season (from June to October) in 2006. Near the center of each plot, the living plant and litter were carefully removed and a top-caped polyvinyl chloride tube with diameter of 4.0 cm was sunk into the soil until a depth of 15 cm for three field incubation cycles, each of which ran for 45 days. At the beginning of each cycle, a pre-incubation soil was sampled near each tube to estimate the initial values of NH_4^+-N and NO_3^--N. The net nitrogen mineralization (μg·g^{-1}) is the increase in NH_4^+-N and NO_3^--N relative to their initial values in the incubation. The net ammonification (μg·g^{-1}) is the increase in NH_4^+-N and net nitrification (μg·g^{-1}) is the increase in NO_3^--N relative to their initial values in the incubation.

In laboratory, after removing roots, a subsample of 45-g fresh soil from each pre- or post-incubation soil sample was mixed with 100 mL of 2 M KCl, shaken for 0.5 h, filtrated, stored and frozen until analysis. At the same time, soil water content was measured for each subsample by oven drying method. The NH_4^+-N and NO_3^--N in the leachate were separately measured by a Bran+Luebbe (AA3) flow injection auto analyzer.

The differences in any of the variables studied for each cycle and general characteristics of topsoil between the adding water plot and the control plot were tested (*t*-test) using SPSS (13.0) for Windows statistical software.

Table 1. General characteristics of topsoil (mean ± standard error of nine measurements) [*]

Soil layer	Bulk density (g·cm^{-3})	pH	Organic matter (g·kg^{-1})	Total N (g·kg^{-1})	Total P (g·kg^{-1})
0-10cm	1.48 ± 0.02	7.48 ± 0.04	6.57 ± 0.31	0.57 ± 0.01	0.09 ± 0.01
10-20cm	1.50 ± 0.01	7.43 ± 0.05	6.55 ± 0.39	0.56 ± 0.02	0.09 ± 0.00

Notes: *---- A paired *t*-test indicated that the difference in each property between two layers was not significant.
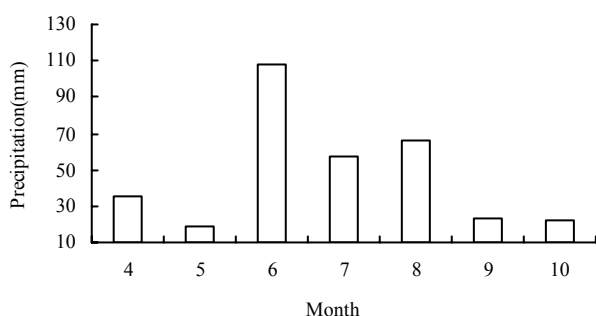

Fig. 1 Pattern of precipitation in 2006

Results and discussion

Net nitrogen nitrification rate and mineralization rate

Net nitrogen nitrification rate over a growing season ranged from 0.97 to 2.1 μg·g^{-1}·month^{-1} in the adding water addition treatment and from 1.02 to 3.49 μg·g^{-1}·month^{-1} in the control treatment (Fig. 2), with the distinct seasonal pattern as that of the net nitrogen nitrification rates. The difference among nitrification rates in the two treatments was not statistically significant ($P > 0.05$) from June to September and significant ($P < 0.05$) from September to October. Comparing with the result of net nitrogen nitrification

rate (0.13–2.68 μg·g^{-1}·month^{-1}) in Zhanggutai sandy plantation from the same region (Chen *et al*. 2006), we thought the net nitrogen nitrification was relatively low in Keerqin sand lands due to climate and soil characters, especially low water capacity of sandy soil. In addition, leaching of nitrate-N was not considered in this study.

The net nitrogen mineralization rates (0.5–4 μg·g^{-1}·month^{-1}) in the two treatments were compared (Fig. 3). The net nitrogen mineralization rate in control plots was higher than that in adding water plots, though the difference was significant ($P < 0.05$) only in the third incubation cycle. This result is in agreement with seasonal studies in the semiarid short grass steppe (MAP 321 mm) where increased soil water content did not result in significant increases in net nitrogen mineralization rates (Hook *et al*. 2000). Similarly, Barrett *et al*. (2002) showed that there was no relationship between in situ net nitrogen mineralization and mean annual precipitation along a spatial precipitation gradient in the Central US grasslands, in spite of the modeled predictions that suggested a linear increase in net nitrogen mineralization rate with increasing rainfall (Burke *et al*. 1997). To assess the direct effects of water availability on litter decomposition and net nitrogen mineralization, Yahdjian *et al*. (2006) conducted a manipulative experiment with rainout shelters in the semiarid Patagonian steppe. Their results also indicated that net nitrogen mineralization rate was not correlated with incoming precipitation.

Converse results had been also reported about semiarid grass-

land. van Oorschot *et al*. (2000) found that soil N-mineralization were positively related to soil moisture content. Not all mineralized nitrogen was available for plant uptake in the wet treatment, as a considerable part was denitrified. Relative N-mineralization was reduced at low water availability. The wet treatment showed that enhanced N-mineralization rates which was most likely the result of the higher soil organic matter decomposition rate were observed. Oomes *et al*. (1997) showed that the high water level lowered the potential nitrogen mineralization in the upper 5 cm of the soil from 16.1 to 4.3 g N m^{-2} and in the deeper 5- to 30-cm layer from 12.6 to 9.4 g N m^{-2} respectively. The total amount of mineral nitrogen that accumulated in the 40-cm-deep soil cores decreased from 31.3 to 15.5 g N m^{-2}.
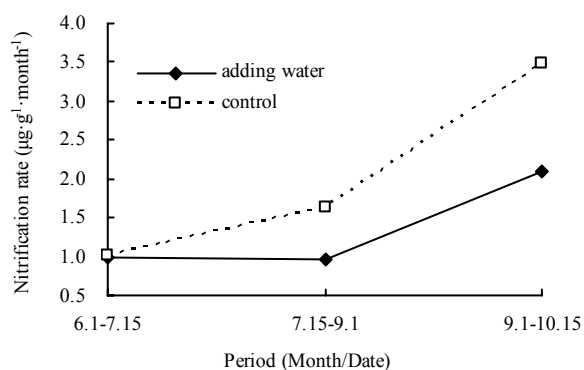

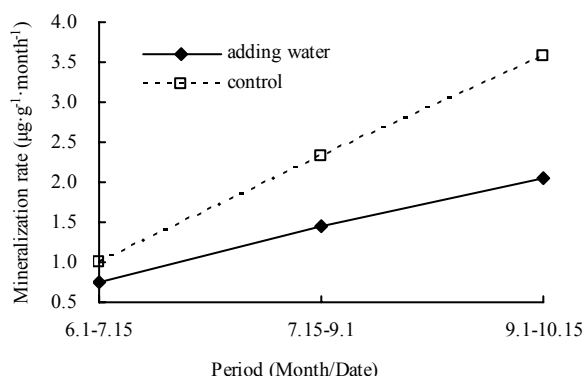**Fig. 2 Net nitrogen nitrification rates from three incubation cycles**

Fig. 3 Net nitrogen mineralization rate from three incubation cycles

It is well thought that method could affect result. Methods used to measure or estimate nitrogen mineralization under field conditions include: (i) exposure of disturbed soil in plastic bags buried in the field, (ii) exposure of relatively undisturbed soil columns under field conditions, and (iii) measurement of mineral nitrogen collected by ion exchange resins placed in the field for extended periods (Raison *et al*. 1987). The in situ closed-top core incubation method may reduce the sources of error due to the disturbance of soil and the modifications of moisture and temperature regimes. By using the PVC soil cores incubation in lab, Wang *et al*. (2004) found that increasing soil moisture and temperature significantly increased net nitrogen mineralization rate in a typical steppe ecosystem in Inner Mongolia, China. Yang *et al*. (2005) also reported that net nitrogen mineralization rate was positively related with soil moisture in *Aneulolepidium chinensis* grassland, Inner Mongolia, China by using ion exchange resin

method.

Biologically available nitrogen (NH_4^+ and NO_3^-) concentrations

Concentrations of NH_4^+ were not affected by water addition ($P > 0.05$; Fig. 4) in growing season in 2006. Seasonal changes of ammonium-N concentrations showed a descending trend, with the least amounts of NH_4^+-N in control plots (0.43 ± 0.19 mg·kg^{-1}) on October 15 and the greatest amounts in adding water plots (1.03 ± 0.14 mg·kg^{-1}) on June 1.

Seasonal change of nitrate-N concentrations showed a ascending trend (Fig. 5). The differences of NO_3^- concentrations of topsoil samples between in adding water plots and in control plots were not significant ($P > 0.05$), with values ranging from 0.75 ± 0.07 mg·kg^{-1} in control plots on July 15 to 2.11 ± 0.65 mg·kg^{-1} in adding water plots on October 15. In this paper, the inorganic nitrogen content in the surface soil layer (0–15 cm) was investigated according to the results of Dodd *et al*. (2000) who found that available nitrogen was greatest in the surface soil layers (0–10 cm) and decreased substantially with depth in the shortgrass steppe.
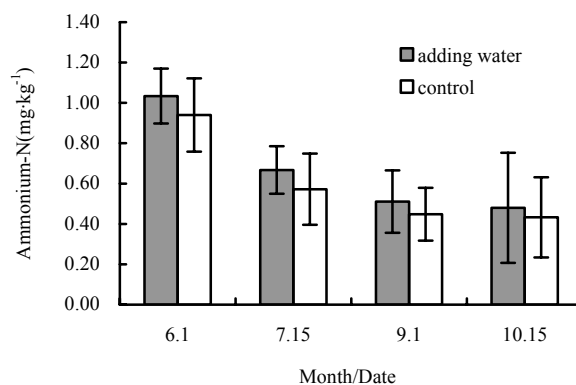

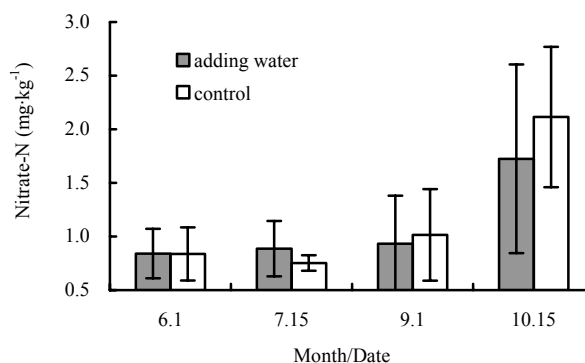**Fig. 4 Seasonal changes of the content of NH_4^+ in topsoil**

Fig. 5 Seasonal changes of the content of NO_3^- in topsoil

Soil inorganic nitrogen contents (NH_4^+-N and NO_3^--N) in soil layer at the depth of 0–15 cm did not show significant effects due to water treatment ($P > 0.05$, Fig. 6). The contents of inorganic-N showed "V" shape variation pattern (from 1.33 ± 0.18 mg·kg^{-1} to 2.55 ± 0.78 mg·kg^{-1}) in growing season in 2006. This is not coincident with the result that soil NO_3^- significantly decreased with increasing precipitation input, whereas soil NH_4^+ concentrations did not differ among precipitation interception

treatments (Yahdjian *et al.* 2006). After analyzing data of precipitation in 2006 (Fig. 1), it is found that the pulse of precipitation was even in growing season and dry season appeared mainly in May. Soil nitrogen availability was mainly limited by the low temperature in May.
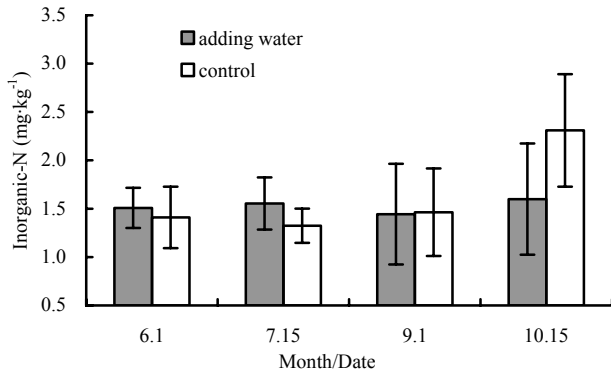

Fig. 6 Seasonal changes of the content of NH$_4^+$ and NO$_3^-$ in topsoil

Conclusions

Soil nitrogen availability (extractable inorganic nitrogen or net nitrogen mineralization rate) in semi-arid grasslands were reported less frequently than nitrogen use efficiency of plant. In our study, soil inorganic nitrogen contents did not exhibit a clear seasonal pattern that was related to the seasonal patterns of soil ammonium-N (ascending trend) and nitrate-N transformation rate (descending trend). The net nitrogen mineralization rates ranged from 0.5 $\mu g \cdot g^{-1} \cdot month^{-1}$ to 4 $\mu g \cdot g^{-1} \cdot month^{-1}$ in Keerqin sandy grasslands. Adding water did not changed soil nitrogen content and net nitrogen mineralization rate in this grassland. The highest values of soil inorganic nitrogen and net nitrogen mineralization rate in control plots occurred on October 15 in 2006, when plants ceased absorbing soil inorganic nitrogen.

Acknowledgements

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